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A REVIEW OF SOME ELECTRON-MICROSCOPIC FRACTOGRAPHIC STUDIES OF ALUMINUM ALLOYS

DEFENSE METALS INFORMATION CENTER

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A REVIEW OF SOME ELECTRON-MICROSCOPIC FRACTOGRAPHIC STUDIES OF ALUMINUM ALLOYS

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INTRODUCTION

Approximately 1 year ago, the Defense Metals Information Center published Memorandum 161 which was a review of the status of electron-microscopic fractography.(1) At that time, electron-microscopic fractography was identified as a useful and promising metallurgical tool expected to find an ever-increasing field of application both in research into fracture mechanisms and in the analysis of service failures. This forecast is proving to be true. In an effort to give the resulting information widespread distribution in the defense industry, and to stimulate additional work in this field, DMIC is undertaking to publish a series of memoranda on various aspects of fractography. These will be short summaries of recent work in areas of current importance and interest. Contributions to these reports from workers in the field are most certainly welcome.

The present memorandum is concerned with the fractography of aluminum alloys under cyclic loading conditions. The first section is a summary of a report which deals with the effect of constituent particles on fatigue crack propagation in 7178 aluminum alloy. The second section contains some recent information on fatigue of aluminum alloys under corrosive conditions.

Constituent Particles in an Aluminum Alloy

A study has been reported recently by Pelloux(2) to evaluate the effect of constituent particles resulting from impurities on fatigue crack propagation in 7178 aluminum alloys. Two alloys of the same nominal composition but differing markedly in impurity content were prepared. The compositions were

Alloy	Composition, per cent								
	Si	Fe	Cu	Mn	Cr	Zn	Be	V	Mg
1936	0.06	0.00	1.48	0.11	0.23	6.47	0.001	0.009	2.61
1939	0.05	0.44	1.53	0.12	0.21	6.51	0.002	0.006	2.61

The large difference in iron content between the two alloys produced a correspondingly large difference in the volume fraction of second-phase particles: 0.30 per cent in alloy 1936 and 4.78 per cent in alloy 1939. These particles consist of Mg_2Si, Al_7Cu_2Fe, and perhaps some Al-Fe-Si remaining from solidification.

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Crack growth rates were determined in two ways. The macroscopic rate of growth was determined from the test data given in terms of the crack length as a function of the number of cycles. The microscopic rate of crack growth was obtained by measuring the spacing of the fatigue striations employing electron-microscopic fractography. As can be seen in Figure 1, two significant observations could be made. First of all, the difference in macroscopic crack growth rate between the two alloys was not as large as would be expected from the difference in cleanliness. Curve A represents the growth rate as a function of crack length for Alloy 1939 while Curve B is the corresponding plot for Alloy 1936. It appeared that a small amount of relatively brittle particles can accelerate the crack almost as much as a large amount of second phase. Secondly, the microscopic growth rate (Curve E) which is the true rate of crack propagation in the matrix, is much less than the macroscopic rate (Curves A and B) and is approximately equal in the two alloys. It was concluded that the macroscopic rate of crack growth is the sum of crack propagation through the matrix plus crack propagation through second-phase particles.

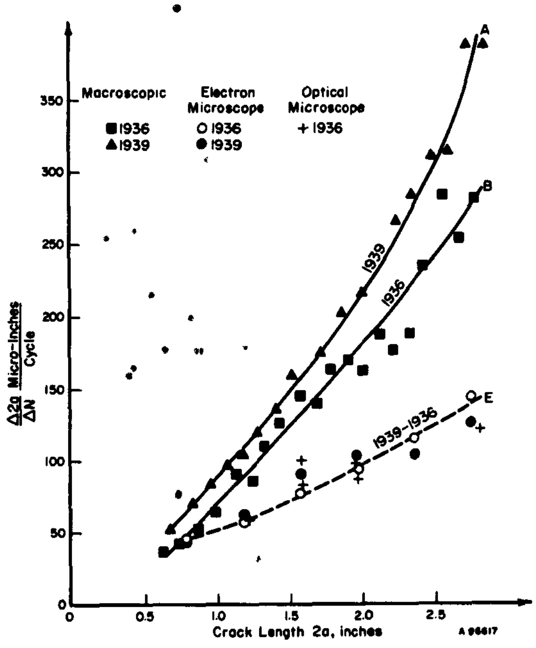


FIGURE 1. RATE OF CRACK GROWTH AS A FUNCTION OF CRACK LENGTH FOR TWO 7178 ALUMINUM ALLOYS(2)

Figures 2 and 3 are typical examples of cases where local cracking due to the constituent particles had accelerated the advancing crack front. In Figure 3, a square array of striations surrounds Particle A indicating that a crack formed at this point quite a distance ahead of the main crack. This crack then grew radially until it joined the main crack by tearing along line CD.

FIGURE 2. FRACTURE SURFACE OF A 7178 ALUMINUM ALLOY (ALLOY 1936)

The brittle fracture of the constituent particles A and B cause a local acceleration of the crack front. Magnification 5000X - the arrow indicates the general direction of crack propagation.(2)

FIGURE 3. FRACTURE SURFACE OF A 7178 ALUMINUM ALLOY (ALLOY 1939)

A crack was formed around the constituent particle A ahead of the main crack front. This crack was extended in a cyclic manner as shown by the striations until it joined the main crack front along a tear line CD. Magnification 5000X - the arrow indicates the general direction of crack propagation.(2)

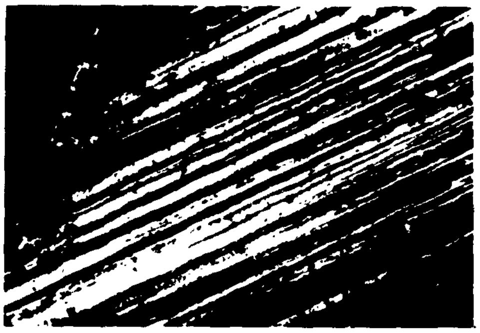
It was proposed that the influence of the constituent particles on rates of crack growth could be explained in terms of the relative magnitude of the size of the plastic zone at the tip of the crack and the interparticle spacing. When the plastic zone is small (i.e., low stress, short crack lengths) the crack growth depends primarily on the properties of the matrix. Note how the matrix growth rate (microscopic) and the total growth rate (macroscopic) intersect at short crack lengths in Figure 1. At intermediate zone sizes (plastic zone sizes approximately equal to the particle spacing), the second-phase particles accelerate the growing crack. At very large plastic zone sizes, the particles control crack growth by the extensive formation of cracks through and around the particles within the plastic zone.

To summarize, this investigation substantiated an earlier hypothesis of Forsyth[3] who said that large intermetallic particles in aluminum alloys may fracture in the vicinity of the crack tip and initiate fatigue cracks in advance of the main crack. Such advance cracking was observed in the presently reported study. It is not to be construed from these results, however, that inclusions or precipitates will accelerate fatigue crack growth in all alloy systems. For example, McEvily has claimed to have observed the opposite effect in Al-Mg-Zn alloys[4] and in Cu-Al-Fe alloys.[5]

Effect of Environment on the Fractographic Appearance of Fatigue Cracks in Aluminum

C. A. Stubbington[6] recently summarized some differences which have been observed between air and corrosion fatigue of an Al-7.5Zn-2.5Mg alloy.[7,8] The alloy was tested in air and under an aqueous 3 per cent NaCl solution, in three conditions of heat treatment: (a) solution treated (840 F; quenched in cold water), (b) fully aged condition [(a) plus 0.1 day at 300 F], and (c) overaged [Condition (a) plus 10 days at 300 F]. Many of the features on the fracture faces in this alloy were large enough and sufficiently flat to be studied by light microscopy and only a limited amount of electron microscopy was employed.

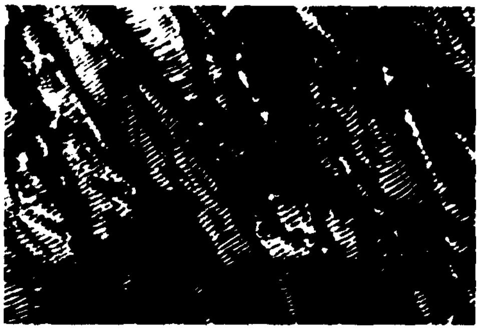
Generally speaking, fatigue fracture has been described as occurring in two stages.[3,7,8,9] Stage I consists of crack growth in the shear mode by a reverse glide mechanism with the fracture plane on or near the planes of maximum shear stress. Figure 4 shows the appearance of a Stage I fracture surface when observed under the microscope. Note the straight, parallel, unevenly spaced striations which lie in the direction of crack growth. Stage II crack growth in the tensile mode produces fracture facets normal to the maximum tensile stress direction which are covered with characteristic fatigue striations. In aluminum, two types of striations are observed during Stage II crack growth and these have been designated Type A and Type B striations. These two types of striations have also been referred to as ductile and brittle striations, respectively, and typical examples of each type are shown in Figures 5 and 6. The Type A or ductile striations appear to be wavelike in nature. It has been shown that considerable plastic deformation is associated with their formation. Type B striations, on the other hand, display an increased proportion of brittle fracture between the striations themselves, and the river patterns usually associated with cleavage fracture are seen superimposed on the



250X

FIGURE 4. Al-7.5Zn-2.5Mg ALLOY, SOLUTION TREATED AND QUENCHED, CORROSION FATIGUE SPECIMEN

Stress ± 9,000 psi; life 3,162,300 cycles. Shear mode fracture surface(6)



500X

FIGURE 5. Al-7.5Zn-2.5Mg ALLOY, SOLUTION TREATED, QUENCHED AND AGED 10 DAYS, AIR FATIGUE SPECIMEN

Stress ± 24,600 psi; life 148,100 cycles. Type A striations on fracture surface(6)

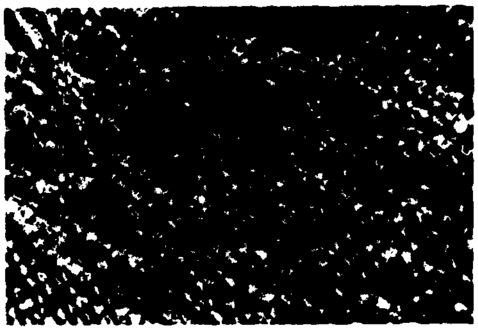


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FIGURE 6. Al-7.5Zn-2.5Mg ALLOY, SOLUTION TREATED, QUENCHED AND AGED 10 DAYS, CORROSION FATIGUE SPECIMEN

Stress ± 24,600 psi; life 96,000 cycles. Type B striations on fracture surface(6)

fracture facets. It has been shown by etch pitting and by X-ray techniques that Type B fracture facets correspond to or are very near (100) crystallographic planes.

In Stubbington's study on Al-7.5Zn-2.5Mg alloy, the following conclusions were reached: In the solution-treated condition and in the fully aged condition, under both air and corrosion fatigue, Stage I and Stage II crack growth were both observed. However, the presence of the corrodant seemed to favor and extend Stage I crack growth. In the overaged condition, when transcrystalline initiation occurred, only Stage II cracking was seen. In some cases, cracking in the overaged alloy initiated intergranularly and appeared to be the result of reversed grain-boundary sliding. Both types of tensile mode striations were distinguished, with Type A occurring predominantly on air-fatigue specimens and Type B being found primarily on the corrosion-fatigue specimens. Triangular areas containing Type A striations were found on the corrosion-fatigue surfaces with the apex of the triangle pointing in the direction of crack growth and the base often lying along a grain boundary. The suggestion was made that ion adsorption may favor Type B striations and crack growth on (100) planes in the case of corrosion fatigue, perhaps by reducing the energy necessary for crack formation on this plane.

Figure 7 is an electron-microscopic fractograph of the fracture origin of a 7075-T6 aluminum alloy forging which failed in a laboratory fatigue test.[10] The faceted appearance of the fracture surface indicates clearly that the crack propagated intergranularly; no evidence of either Type A or Type B striations was observed. It was concluded that failure resulted from stress-corrosion cracking and final fracture occurred when the stress-corrosion crack penetrated to a sufficient depth for the remaining material to fail catastrophically. In this case, the presence of a corrosive environment did not simply change the appearance of the fatigue striations, but a complete change in fracture mode from transgranular to intergranular occurred.

6000X

FIGURE 7. INTERGRANULAR FRACTURE IN THE CRACK-INITIATION REGION OF A 7075-T6 ALUMINUM ALLOY FORGING WHICH FAILED IN A FATIGUE TEST.(10)

REFERENCES

(1) Warke, W. R., and Elsea, A. R., "Electron Microscopic Fractography", DMIC Memorandum 161 (December 21, 1962).

(2) Pelloux, R. M. N., "Influence of Constituent Particles on Fatigue Crack Propagation in Aluminum Alloys", Boeing Scientific Research Laboratories, Report D1-82-0297 (September, 1963).

(3) Forsyth, P. J. E., "A Two Stage Process of Fatigue Crack Growth", Proceedings of the Crack Propagation Symposium, Cranfield, College of Aeronautics (1961).

(4) Glassman, L. H., and McEvily, A. J., "Effect of Constituent Particles on the Notch Sensitivity and Fatigue-Crack-Propagation Characteristics of Aluminum-Zinc-Magnesium Alloys", NASA TN D-928 (1962).

(5) McEvily, A. J., and Boettner, R. C., "On Fatigue Crack Propagation in F.C.C. Metals", Acta Met., 11 (7), 725 (July, 1963).

(6) Stubbington, C. A., "Some Observations on Air and Corrosion Fatigue of an Aluminum-7.5%Zinc-2.5%Magnesium Alloy", Metallurgia, 68 (407), 109 (September, 1963).

(7) Forsyth, P. J. E., Stubbington, C. A., and Clark, D., "Cleavage Facets Observed on Fatigue Fracture Surfaces in an Aluminum Alloy", J. Inst. Metals, 90, 238 (1961-62).

(8) Stubbington, C. A., and Forsyth, P. J. E., "Some Corrosion Fatigue Observations on a High-Purity Aluminum-Zinc-Magnesium Alloy and Commercial DTD 683 Alloy", J. Inst. Metals, 90, 347 (1961-62).

(9) Forsyth, P. J. E., "Fatigue Damage and Crack Growth in Aluminum Alloys", Acta Met., 11 (7), 703 (July, 1963).

(10) Dahlberg, E. P., "Fractography Part XI, Examination of a 7075 T-6 Aluminum Alloy Forging Fracture", U. S. Naval Research Laboratory Memorandum Report 1427 (June, 1963).

LIST OF DMIC MEMORANDA ISSUED
(Continued)

A list of DMIC Memoranda 1-164 may be obtained from DMIC, or see previously issued memoranda.

DMIC Memorandum Number	Title
165	Review of Uses for Depleted Uranium and Nonenergy Uses for Natural Uranium, February 1, 1963
166	Literature Survey on the Effect of Sonic and Ultrasonic Vibrations in Controlling Grain Size During Solidification of Steel Ingots and Weldments, May 15, 1963
167	Notes on Large-Size Furnaces for Heat Treating Metal Assemblies, May 24, 1963 (A Revision of DMIC Memo 63)
168	Some Observations on the Arc Melting of Tungsten, May 31, 1963
169	Weldability Studies of Three Commercial Columbium-Base Alloys, June 17, 1963
170	Creep of Columbium Alloys, June 24, 1963
171	A Tabulation of Designations, Properties, and Treatments of Titanium and Titanium Alloys, July 15, 1963
172	Production Problems Associated with Coating Refractory Metal Hardware for Aerospace Vehicles, July 26, 1963
173	Reactivity of Titanium with Gaseous N_2O_4 Under Conditions of Tensile Rupture, August 1, 1963
174	Some Design Aspects of Fracture in Flat Sheet Specimens and Cylindrical Pressure Vessels, August 9, 1963
175	Consideration of Steels with Over 150,000 psi Yield Strength for Deep-Submergence Hulls, August 16, 1963
176	Preparation and Properties of Fiber-Reinforced Structural Materials, August 22, 1963
177	Designations of Alloys for Aircraft and Missiles, September 4, 1963
178	Some Observations on the Distribution of Stress in the Vicinity of a Crack in the Center of a Plate, September 18, 1963
179	Short-Time Tensile Properties of the Co-20Cr-15W-10Ni Cobalt-Base Alloy, September 27, 1963
180	The Problem of Hydrogen in Steel, October 1, 1963
181	Report on the Third Maraging Steel Project Review, October 7, 1963
182	The Current Status of the Welding of Maraging Steels, October 16, 1963
183	The Current Status and 1970 Potential for Selected Defense Metals, October 31, 1963
184	A Review and Comparison of Alloys for Future Solid-Propellant Rocket-Motor Cases, November 15, 1963
185	Classification of DMIC Reports and Memoranda by Major Subject, January 15, 1964
186	A Review of Some Electron-Microscopic Fractographic Studies of Aluminum Alloys, February 5, 1964